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ENGINE COMPONENT PART AND METHOD FOR PRODUCING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the invention

The present invention relates to an engine component, e.g., a cylinder block or a piston, and a method for producing the same. More particularly, the present invention relates to an engine component composed of an aluminum alloy which includes silicon, and a method for producing the same. The present invention also relates to an engine and an automotive vehicle incorporating such an engine component.

2. Description of the Related Art

In recent years, in an attempt to reduce the weight of engines, there has been a trend to use an aluminum alloy for cylinder blocks. Since a cylinder block is required to have a high strength and high abrasion resistance, aluminum alloys which contain a large amount of silicon are expected to be promising aluminum alloys for cylinder blocks.

In general, an aluminum alloy which contains a large amount of silicon is difficult to cast, thus making die casting-based mass production difficult. Accordingly, the inventors of the present invention have proposed a high-pressure die casting technique which enables mass production of cylinder blocks using such aluminum alloys (see the pamphlet of WO 2004/002658). This technique makes it possible to mass produce cylinder blocks which have sufficient abrasion resistance and strength for practical use.

However, depending on the conceivable engine revolution and the conceivable conditions under which an engine may be used, a cylinder block may meet with even higher abrasion resistance and strength requirements. For example, in the case of a motorcycle, its engine is operated at a revolution of 7,000 rpm or more, so that there exist fairly high abrasion resistance and strength requirements for the cylinder block.

SUMMARY OF THE INVENTION

In order to overcome the problems described above, preferred embodiments of the present invention provide an engine component which has excellent abrasion resistance and strength, as well as a method for producing such a novel engine component.

An engine component according to a preferred embodiment of the present invention is composed of an aluminum alloy containing silicon including a plurality of primary-crystal silicon grains located on a slide surface, wherein the plurality of primary-crystal silicon grains have an average crystal grain size of no less than about 12 μ m and no more than about 50 μ m. With this unique structure, the advantages and solutions described above are achieved.

In a preferred embodiment, the engine component further includes a plurality of eutectic silicon grains formed between the plurality of primary-crystal silicon grains, wherein the plurality of eutectic silicon grains have an average crystal grain size of no more than about 7.5 μ m. With this unique structure, the advantages and solutions

described above are achieved.

In a preferred embodiment, the engine component having the aforementioned structure is a cylinder block, wherein the plurality of primary-crystal silicon grains are exposed on a surface of a cylinder bore wall.

Alternatively, the engine component according to another preferred embodiment of the present invention is composed of an aluminum alloy containing silicon including a plurality of silicon crystal grains located on a slide surface, wherein the plurality of silicon crystal grains have a grain size distribution having at least two peaks; and the at least two peaks include a first peak existing in a crystal grain size range of no less than about 1 μm and no more than about 7.5 μm and a second peak existing in a crystal grain size range of no less than about 12 μm and no more than about 50 μm. With this unique structure, the advantages and solutions described above are achieved.

In a preferred embodiment, in any arbitrary rectangular region of the slide surface having an approximate size of 800 μ m × 1000 μ m, the number of circular regions having a

diameter of approximately 50 μm and not containing any silicon crystal grains of a crystal grain size of about 0.1μm or more is equal to or less than five.

In a preferred embodiment, the aluminum alloy contains: no less than about 73.4wt% and no more than about 79.6wt% of aluminum; no less than about 18wt% and no more than about 22wt% of silicon; and no less than about 2.0wt% and no more than about 3.0wt% of copper.

In a preferred embodiment, the aluminum alloy contains: no less than about 50 wtppm and no more than about 200 wtppm of phosphorus; and no more than about 0.01wt% of calcium.

In a preferred embodiment, the slide surface has a Rockwell hardness (HRB) of no less than about 60 and no more than about 80.

An engine according to a preferred embodiment of the present invention includes the engine component having the aforementioned structure. With this unique structure, the advantages and solutions described above are achieved.

A cylinder block according to a preferred embodiment of the present invention is a cylinder block composed of an

aluminum alloy containing: no less than about 73.4wt% and no more than about 79.6wt% of aluminum; no less than 18wt% and no more than about 22wt% of silicon; and no less than about 2.0wt% and no more than about 3.0wt% of copper, the cylinder block including a plurality of primary-crystal silicon grains located on a slide surface arranged to come in contact with a piston, and a plurality of eutectic silicon grains disposed between the plurality of primary-crystal silicon grains, wherein, the plurality of primary-crystal silicon grains have an average crystal grain size of no less than about 12 μ m and no more than about 50 μ m, and the plurality of eutectic silicon grains have an average crystal grain size of no more than about 7.5 μ m; the aluminum alloy contains: no less than about 50 wtppm and no more than about 200 wtppm of phosphorus; and no more than about 0.01wt% of calcium; and the slide surface has a Rockwell hardness (HRB) of no less than about 60 and no more than about 80. With this unique structure, the advantages and solutions described above are achieved.

Alternatively, the cylinder block according to a preferred embodiment of the present invention is a cylinder

block composed of an aluminum alloy containing: no less than about 73.4wt% and no more than about 79.6wt% of aluminum; no less than about 18wt% and no more than about 22wt% of silicon; and no less than about 2.0wt% and no more than about 3.0wt% of copper, the cylinder block including a plurality of silicon crystal grains formed on a slide surface to come in contact with a piston, wherein, the plurality of silicon crystal grains have a grain size distribution having at least two peaks; the at least two peaks include a first peak existing in a crystal grain size range of no less than about 1 μm and no more than about 7.5 μm and a second peak existing in a crystal grain size range of no less than about 12 μm and no more than about 50 μm; in any arbitrary rectangular region of the slide surface sized about 800 μ m×1000 μ m, the number of circular regions having a diameter of about 50 μ m and not containing any silicon crystal grains of a crystal grain size of about 0.1 μ m or more is equal to or less than five; the aluminum alloy contains: no less than about 50 wtppm and no more than about 200 wtppm of phosphorus; and no more than about 0.01wt% of calcium; and the slide surface has a

Rockwell hardness (HRB) of no less than about 60 and no more than about 80. With this unique structure, the advantages and solutions described above are achieved.

Alternatively, the engine according to a preferred embodiment of the present invention includes the cylinder block having the aforementioned structure; and a piston having a slide surface whose surface hardness is higher than that of the slide surface of the cylinder block. With this unique structure, the advantages and solutions described above are achieved.

An automotive vehicle according to yet another preferred embodiment of the present invention includes the engine having the aforementioned structure. With this unique structure, the advantages and solutions described above are achieved.

A method for producing a slide component for an engine according to a preferred embodiment of the present invention includes step (a) of preparing an aluminum alloy containing: no less than about 73.4wt% and no more than about 79.6wt% of aluminum; no less than about 18wt% and no more than about

22wt% of silicon; and no less than about 2.0wt% and no more than about 3.0wt% of copper; step (b) of cooling a melt of the aluminum alloy in a mold to form a molding; step (c) of subjecting the molding to a heat treatment at a temperature of no less than about 450℃ and no more than about 520℃for a period of no less than about three hours and no more than about five hours, and thereafter liquid-cooling the molding; and step (d) of, after step (c), subjecting the molding to a heat treatment at a temperature of no less than about 180℃ and no more than about 220℃ for a period of no less than about three hours and no more than about five hours, wherein step (b) of forming the molding is performed so that an area of a slide surface is cooled at a cooling rate of no less than about 4℃/sec and no more than about 50℃/sec. With this unique structure, the advantages and solutions described above are achieved.

In a preferred embodiment, step (b) of forming the molding includes step (b-1) of allowing a plurality of primary-crystal silicon grains to be formed in the area of the slide surface so as to have an average crystal grain size

of no less than about 12 μm and no more than about 50 μm; and step (b-2) of allowing a plurality of eutectic silicon grains to be formed between the plurality of primary-crystal silicon grains so as to have an average crystal grain size of no more than about 7.5 μm.

According to various preferred embodiments of the present invention, there is provided an engine component which has excellent abrasion resistance and strength, as well as a method for producing the same.

Other features, elements, processes, steps, characteristics and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments of the present invention with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view schematically showing a cylinder block **100** according to a preferred embodiment of the present invention;

FIG. **2** is a schematic enlarged view of a slide surface

of the cylinder block **100**;

FIGS. **3A**, **3B**, and **3C** are diagrams for explaining the relationship between an average crystal grain size of primary-crystal silicon grains and the abrasion resistance of a cylinder block;

FIG. **4** is a flowchart illustrating a method for producing the cylinder block **100**;

FIG. **5** is a schematic diagram showing a high-pressure die cast apparatus used for casting the cylinder block **100**;

FIGS. **6A** and **6B** are metallurgical microscope photographs of a slide surface of a comparative cylinder block, which was cast by using a sand mold;

FIGS. **7A** and **7B** are metallurgical microscope photographs of a slide surface of a prototype cylinder block, which was cast via high-pressure die cast;

FIG. **8** is a graph showing a grain size distribution of silicon crystal grains formed on the slide surface of the comparative cylinder block;

FIG. **9** is a graph showing a grain size distribution of silicon crystal grains formed on the slide surface of the

prototype cylinder block;

FIG. **10** is an enlarged photograph of the slide surface of the comparative cylinder block after being subjected to an abrasion test;

FIG. **11** is an enlarged photograph of the slide surface of the prototype cylinder block after being subjected to an abrasion test;

FIG. **12** is a photograph showing a silicon crystal grain which has become gigantic due to a micronization effect of phosphorus being hindered by calcium;

FIG. **13** is a cross-sectional view schematically showing a mechanism as to how lubricant may be retained in oil pockets on the slide surface;

FIGS. **14A** to **14E** are metallurgical microscope photographs each showing a slide surface of a cylinder block, the cylinder blocks having been cast under respectively different cooling rate conditions;

FIG. **15** is a graph showing a relationship between temperature and time after a casting process is begun;

FIG. **16** is a cross-sectional view schematically showing

an engine **150** having the cylinder block **100**; and

FIG. **17** is a side view schematically showing a motorcycle having the engine **150** shown in FIG. **16**.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The inventors have conducted a detailed study of the relationship between the mode or style of silicon crystal grains on a slide surface (i.e., a surface which comes in contact with a piston) of a cylinder block and the abrasion resistance and strength of the cylinder block. As a result, the inventors have discovered that the abrasion resistance and strength can be greatly improved by setting the average crystal grain size of the silicon crystal grains so as to fall within a specific range, and/or ensuring that the silicon crystal grains have a specific grain size distribution. The present invention has been developed based on this discovery information.

Moreover, the inventors have also investigated conditions for producing cylinder blocks, and thus arrived at a preferable production method which allows silicon crystal

grains to be formed on the slide surface in the aforementioned preferable mode or style.

Hereinafter, preferred embodiments of the present invention will be described with reference to the drawings. Although the following description will mainly concern a cylinder block as an example, the present invention is not limited to such. The present invention can be suitably applied to a slide component for an engine, the slide component being a component (e.g., a cylinder block or a piston) of a combustion chamber of an internal combustion engine, and a method for producing the same.

FIG. **1** shows a cylinder block **100** according to the present preferred embodiment. The cylinder block **100** is formed of an aluminum alloy which contains silicon.

As shown in FIG. **1**, the cylinder block **100** preferably includes a wall portion (referred to as a "cylinder bore wall") **103** defining the cylinder bore **102**, and a wall portion (referred to as a "cylinder block outer wall") **104** surrounding the cylinder bore wall **103** and defining the outer contour of the cylinder block **100**. Between the cylinder bore

wall **103** and the cylinder block outer wall **104**, a water jacket **105** for retaining a coolant is provided.

The surface **101** of the cylinder bore wall **103** facing the cylinder bore **102** defines a slide surface which comes into contact with a piston. The slide surface **101** is shown enlarged in FIG. **2**.

As shown in FIG. **2**, the cylinder block **100** includes a plurality of silicon crystal grains **1011** and **1012**, which have been formed and are located on the slide surface **101**. These silicon crystal grains **1011** and **1012** are dispersed in a matrix **1013** of solid solution which contains aluminum.

The silicon crystal grains which are the first to crystallize when a melt of an aluminum alloy which has a hypereutectic composition containing a large amount of silicon are referred to as "primary-crystal silicon grains". The silicon crystal grains which crystallize then are referred to as "eutectic silicon grains". Among the silicon crystal grains **1011** and **1012** shown in FIG. **2**, the relatively large silicon crystal grains **1011** are the primary-crystal silicon grains. The relatively small silicon crystal grains

1012 formed between the primary-crystal silicon grains are the eutectic silicon grains.

The eutectic silicon grains **1012** are typically needle-like crystals as shown in FIG. **2**; however, not every eutectic silicon crystal grain **1012** is a needle-like crystal. In actuality, some of the eutectic silicon grains **1012** are likely to be granular crystals. The primary-crystal silicon grains **1011** are mainly composed of granular crystals, whereas the eutectic silicon grains **1012** are mainly composed of needle-like crystals.

The inventors have experimentally found that the abrasion resistance and strength of the cylinder block **100** can be greatly improved by prescribing the average crystal grain size of the primary-crystal silicon grains **1011** to be within a range of no less than about 12 μm and no more than about 50 μm. The detailed experimental results will be described later. For now, the reason why a considerable improvement of the abrasion resistance and strength can be achieved by setting the aforementioned range of average crystal grain size will be described with reference to FIGS.

3A to **3C**.

If the average crystal grain size of the primary-crystal silicon grains **1011** exceeds about 50 μ m, as shown at the left-hand side of FIG. **3A**, the number of primary-crystal silicon grains **1011** per unit area of the slide surface **101** is small. Therefore, a large load is imposed on each primary-crystal silicon crystal grain **1011** during engine operation, so that, as shown at the right-hand side of FIG. **3A**, the primary-crystal silicon grains **1011** may possibly be destroyed. If the primary-crystal silicon grains **1011** are destroyed, a film of lubricant which has been formed on the slide surface **101** will be broken, thus allowing a piston ring or piston to come into direct contact with the matrix **1013** of the slide surface **101**, resulting in scuffs. Furthermore, the debris of the destroyed primary-crystal silicon grains **1011** will act as abrasive grains, thus causing considerable abrasion of the slide surface **101**.

If the average crystal grain size of the primary-crystal silicon grains **1011** is less than about 12 μ m, as shown at the left-hand side of FIG. **3B**, only a small portion of each

primary-crystal silicon crystal grain **1011** is buried in the matrix **1013**. Therefore, as shown at the right-hand side of FIG. **3B**, the primary-crystal silicon grains **1011** may easily be removed during engine operation. Such stray primary-crystal silicon grains **1011** will act as abrasive grains due to their high hardness, thus causing considerable abrasion of the slide surface **101**. Moreover, the portion of each primary-crystal silicon crystal grain **1011** rising above the matrix **1013** is also small in this case, so that the thickness of the lubricant film to be retained on the slide surface **101** will be reduced. As a result, breaking of the lubricant film may easily occur, thus resulting in scuffs.

On the other hand, if the average crystal grain size of the primary-crystal silicon grains **1011** is no less than 12 μm and no more than about 50 μm, as shown at the left-hand side of FIG. **3C**, an adequate number of primary-crystal silicon grains **1011** exist per unit area of the slide surface **101**. Therefore, the load on each primary-crystal silicon crystal grain **1011** during engine operation becomes relatively small so that, as shown at the right-hand side of FIG. **3C**,

the primary-crystal silicon grains **1011** are prevented from being destroyed. Moreover, in this case, the portion of each primary-crystal silicon crystal grain **1011** rising above the matrix **1013** has a sufficient height, which makes possible the retention of a sufficient amount of lubricant. Thus, a lubricant film having a sufficient thickness can be retained on the slide surface **101**, whereby breaking of the lubricant film, and hence generation of scuffs, can be prevented. Since the portion of each primary-crystal silicon crystal grain **1011** that is buried in the matrix **1013** is sufficiently large, the primary-crystal silicon grains **1011** are prevented from coming off. Therefore, abrasion of the slide surface **101** due to stray primary-crystal silicon grains can be prevented.

Moreover, the inventors studied how the eutectic silicon grains **1012** reinforce the matrix **1013** to discover that, by micronizing the eutectic silicon grains **1012**, it is possible to improve the abrasion resistance and strength of the cylinder block **100**. Specifically, improvement of abrasion resistance and strength can be obtained by ensuring that the

eutectic silicon grains **1012** have an average crystal grain size of no more than about 7.5 μ m.

Furthermore, the inventors have also examined the grain size distribution of the plurality of silicon crystal grains formed at the slide surface **101**, to discover that a considerable improvement in the abrasion resistance and strength of the cylinder block **100** can be obtained by ensuring that the plurality of silicon crystal grains have a grain size distribution such that a peak exists in the crystal grain size range of no less than about 1 μ m and no more than about 7.5 μ m and another peak exists in the crystal grain size range of no less than about 12 μ m and no more than about 50 μ m.

With the cylinder block **100** of the present preferred embodiment of the present invention, as described above, the silicon crystal grains which are formed at the slide surface **101** achieve a high abrasion resistance, to such an extent that it is as if an anti-abrasion layer were formed at the inner surface of the cylinder bore wall **103**. This "anti-abrasion layer" also improves the strength of the cylinder

bore wall **103**.

There is a known technique for improving the abrasion resistance of a cylinder block which involves placing a cylinder sleeve within the cylinder bore. However, with such a technique, it is difficult to ensure complete contact between the cylinder sleeve and the cylinder block itself, thus resulting in a deteriorated thermal conductivity. Moreover, the thickness of the cylinder sleeve itself adds to the overall thickness of the cylinder bore wall, thus deteriorating the cooling performance.

On the other hand, in accordance with the cylinder block **100** of the present preferred embodiment, an anti-abrasion layer, which also serves to provide an improved strength, is formed integrally with the cylinder bore wall **103**. As a result, deterioration in thermal conductivity is prevented, and the thickness of the cylinder bore wall **103** itself can be reduced, thus making for an improved cooling performance. Furthermore, the improved cooling performance of the cylinder block **100** allows for an increase in the amount of gas mixture (which in the case of direct injection is air) that can be

taken into the cylinder, whereby the engine output power can be enhanced.

Next, a production method which can be suitably used for the production of the cylinder block **100** will be described with reference to FIG. **4**. FIG. **4** is a flowchart illustrating a method for producing the cylinder block of the present preferred embodiment.

First, a silicon-containing aluminum alloy is prepared (step **S1**). In order to ensure a sufficient abrasion resistance and strength of the cylinder block **100**, it is preferable to use an aluminum alloy which contains: no less than about 73.4wt% and no more than about 79.6wt% of aluminum; no less than about 18wt% and no more than about 22wt% of silicon; and no less than about 2.0wt% and no more than about 3.0wt% of copper. The aluminum alloy may be produced from a virgin bulk of aluminum, or from a recovered bulk of aluminum alloy.

Next, the prepared aluminum alloy is heated and melted in a melting furnace, whereby a melt is formed (step S2). At this time, in order to prevent any unmelted silicon from

being left in the melt, the melt is heated to a predetermined temperature or higher. Once the aluminum alloy is completely melted, the melt is retained at a reduced temperature in order to prevent oxidation and gas absorption. It is preferable that phosphorus be added to the ingot or melt, at about 100 wtppm, before the melting. If the aluminum alloy contains no less than about 50 wtppm and no more than about 200 wtppm of phosphorus, it becomes possible to reduce the tendency of the silicon crystal grains to become gigantic, thus allowing for uniform dispersion of the silicon crystal grains within the alloy.

Next, casting is performed by using the aluminum alloy melt (step S3). In other words, the melt is cooled within a mold to form a molding. This step of molding formation is performed in such a manner that the area of the slide surface is cooled at a cooling rate of no less than about 4℃/sec and no more than about 50℃/sec. The specific structure of a cast apparatus to be used in this step will be described later.

Next, the cylinder block **100** which has been taken out of

the mold is subjected to one of the heat treatments commonly known as "T5", "T6", and "T7" (step S4). A T5 treatment is a treatment in which the molding is rapidly cooled (with water or the like) immediately after being taken out of the mold, and thereafter subjected to artificial aging at a predetermined temperature for a predetermined period of time to obtain improved mechanical properties and dimensional stability, followed by air cooling. A T6 treatment is a treatment in which the molding is subjected to a solution treatment at a predetermined temperature for a predetermined period after being taken out of the mold, then cooled with water, and thereafter subjected to artificial aging at a predetermined temperature for a predetermined period of time, followed by air cooling. A T7 treatment is a treatment for causing a stronger degree of aging than in the T6 treatment; although the T7 treatment can ensure better dimensional stability than does the T6 treatment, the resultant hardness will be lower than that obtained from the T6 treatment.

Next, predetermined machining is performed for the cylinder block **100** (step S5). Specifically, a surface

abutting with a cylinder head, a surface abutting with a crankcase, and the inner surface of the cylinder bore wall **103** are ground, turned, and so on.

Thereafter, the inner surface (i.e., a surface defining the slide surface **101**) of the cylinder bore wall **103** is subjected to a honing process (step **S6**), whereby the cylinder block **100** is completed. A honing process can be performed, for example, in three steps of coarse honing, medium honing, and finish honing.

As described above, in accordance with the production method of the present preferred embodiment, the molding formation step is performed in such a manner that the area of the slide surface is cooled at a cooling rate of no less than about 4℃/sec and no more than about 50℃/sec. Therefore, as can be seen from a prototype cylinder block according to a preferred embodiment of the present invention which is described below, the average crystal grain size of the primary-crystal silicon grains **1011** formed on the slide surface **101** can be confined within the range of no less than about 12 μ m and no more than about 50 μ m. Moreover, as

also seen from the below-described prototype, it is ensured that the average crystal grain size of the eutectic silicon grains **1012** formed between the primary-crystal silicon grains **1011** is equal to or less than about 7.5 μm. Thus, in accordance with the production method of the present preferred embodiment, a cylinder block **100** which has excellent abrasion resistance and strength can be produced.

As the heat treatment step, it is particularly preferable to perform a T6 treatment. Furthermore, it is preferable that the heat treatment step (T6 treatment step) include: a step of subjecting the molding to a heat treatment at a temperature of no less than about 450℃ and no more than about 520℃ for no less than about three hours and no more than about five hours, and then performing a liquid cooling (first heat treatment step); and a subsequent step of subjecting the molding to a heat treatment at a temperature of no less than about 180℃ and no more than about 220℃ for no less than about three hours and no more than about five hours (second heat treatment step).

The first heat treatment step allows any compound of

aluminum and copper which exists within the alloy to be decomposed so that the copper atoms become dispersed within the matrix **1013**, and the subsequent second heat treatment step allows these copper atoms to cohere within the matrix **1013**. This cohesion state is also referred to as a coherent precipitation state. By effecting such a coherent precipitation of copper atoms within the matrix **1013**, the strength of the matrix **1013** retaining the silicon crystal grains **1011** and **1012** is improved. Since the first heat treatment step allows the needle-like eutectic silicon grains **1012** to be dispersed within the matrix **1013**, the supporting force (i.e., a force which supports the silicon crystal grains) of the matrix **1013** is improved, whereby an effect of preventing removal of the silicon crystal grains can also be attained.

Now, a cast apparatus to be used for the casting process (step **S3** in FIG. **4**) will be described. FIG. **5** shows a high-pressure die cast apparatus used for the casting process. The high-pressure die cast apparatus shown in FIG. **5** includes a die **1** and a cover **14** which covers the entire die **1**.

The die **1** is composed of a stationary die **2** which remains fixed, and a movable die **3** which has movable portions. The movable die **3** includes a base die **4** and a slide die **5**. These dies are formed of a material which is selected with consideration to cooling efficiency; for example, these dies may be formed of an iron alloy (e.g., JIS-SKD61) to which silicon and vanadium have been added each at about 1%.

First, the die structure is described. The slide die **5** is split into four portions at every 90°, such that each split portion has a cylinder **6** (only two such cylinders **6** are shown in FIG. **5**). By the action of the cylinder **6**, each split portion of the slide die **5** slides along a direction denoted by arrow **A** in FIG. **5**, upon a surface **30** of the base die **4** facing the slide die **5** (i.e., the abutting surface with the slide die **5**), so as to form a cavity **7** corresponding to the cylinder block in a central portion at the time of casting.

In the central portion of the cavity **7**, a cylinder bore forming portion **7a** for forming a cylinder bore is provided. In the illustrated high-pressure die cast apparatus, the

cylinder bore forming portion **7a** is formed so as to be integral with the base die **4**; at casting, a tip **7b** thereof abuts with a surface of the stationary die **2** facing the movable die **3**, as shown. Within the cavity **7**, a core **7c** for forming a water jacket is provided. The core **7c** is formed separately from the base die **4**, and thus is removable therefrom.

The base die **4** is provided with an extrusion pin **8**. For each shot, a molding is extruded by the extrusion pin **8**, with the slide die **5** being open, whereby the molding is taken out from the die **1**.

Next, a melt-feeding system will be described. The stationary die **2** is provided with an injection sleeve **9**. Within the injection sleeve **9**, a plunger tip **11** which is provided at the tip end of a rod **10** reciprocates. A melt-feeding inlet **12** is formed in the injection sleeve **9**. While the plunger tip **11** is in an original position (i.e., "behind", or to the right (as shown in FIG. **5**) of the melt-feeding inlet **12**), one shot's worth of melt is injected through the melt-feeding inlet **12**. Ahead of the melt-feeding inlet **12** is

provided a tip sensor **13**. The tip sensor **13** detects passage of the plunger tip **11** past the melt-feeding inlet **12**. As the plunger tip **11** extrudes the melt, the cavity **7** is filled with the melt.

The cover **14** includes a first cover element **14a** for accommodating the stationary die **2** and a second cover element **14b** for accommodating the movable die **3**. In order to maintain air tightness within the cover **14**, a sealing member **15**, such as an O ring, is mounted on a surface **32** of the first cover element **14a** that abuts with the second cover element **14b**. A sealing member **15** such as an O ring is also mounted at any interspace between the cover **14** and each of the cylinder **6**, the extrusion pin **8**, and the injection sleeve **9** penetrating through the cover **14**. A leak valve **16** for exposing the interior of the cover **14** to the atmosphere is provided on the second cover element **14b**. Alternatively, the leak valve **16** may be provided on the first cover element **14a**.

In the stationary die **2**, a ventilation passage **17** which communicates with the cavity **7** is formed. Within the ventilation passage **17**, an ON/OFF valve **18** is provided, with

a bypass passage **17a** being formed so as to avoid the portion where the ON/OFF valve **18** is provided. The bypass passage **17a** is provided in order to allow the ventilation passage **17** to communicate with the exterior of the die **1** when a vacuum suction is performed in the die **1** at casting (i.e., in the state as shown in FIG. **5**). The bypass passage **17a** and the ventilation passage **17** are closed or opened as the ON/OFF valve **18** moves in the upper or lower direction in FIG. **5**. The ON/OFF valve **18** is energized with a spring so that the passage normally stays open. Alternatively, the ventilation passage **17** may be formed on the movable die **3**.

The ON/OFF valve **18** is a valve of a metal-touch type, for example. Once the cavity **7** is filled with melt, the excess melt will move up the ventilation passage **17**, until the melt touches the ON/OFF valve **18** so as to push up the ON/OFF valve **18**. As a result, the bypass passage **17a** is closed together with the ventilation passage **17**, thus preventing the melt from spurting out of the die **1**.

Instead of such a metal-touch type valve, a valve may alternatively be used which detects the position of the

plunger tip **11** and closes the ventilation passage **17**, by an actuator, when thrusting of one shot of melt is completed.

Alternatively, a chill-vent structure may be used to prevent the melt from spurting out. In a chill-vent structure, a thin, elongated passage of a zigzag shape is formed to communicate with the cavity **7**. Any melt that overflows the cavity **7** is allowed to solidify midway through this passage, whereby the melt is prevented from spurting out of the die **1**.

In order to minimize the amount of air which strays into the molding, it is necessary to place the interior of the cavity **7** in a decompressed state prior to feeding of the melt. To the cover **14** (or more specifically, the first cover element **14a** in this example), one or more (i.e., two in this example) vacuum ducts **20** which communicate with a vacuum tank **19** are connected. The vacuum tank **19** is maintained at a predetermined vacuum pressure by a vacuum pump **21**. A solenoid valve **20a** which is installed in each vacuum duct **20** is controlled by a control device **22** so as to be opened or closed. Specifically, the control device **22** controls the

opening/closing in accordance with the start/end timing of decompression of the cavity **7**, based on a detection signal of a stroke position of the plunger tip **11**, a timer signal concerning stroke time, or the like.

Although the present preferred embodiment illustrates an example where the cover **14** covers the entire die **1**, the cover **14** may alternatively cover only a portion of the die **1**. For example, an outer periphery of the die **1** may be covered in an annular fashion, along peripheries **30a** and **31a**, respectively, of the abutting surface **30** of the base die **4** with the slide die **5** and the abutting surface **31** of the slide die **5** with the stationary die **2**. Alternatively, a cover shaped so as to cover the cylinder **6** for driving the slide die **5** may be provided.

Thus, in accordance with the high-pressure die cast apparatus of the present preferred embodiment, the cover **14** is arranged so as to cover the die **1**, and the interior of the cover **14** is evacuated. By thus decompressing the interior of the cavity **7**, casting is performed. Therefore, even in the case where the slide die **5** is split into a large number of

portions, it is still possible to perform a vacuum suction for the entire die **1**, without having to provide sealing for the die **1** itself. Since a vacuum suction for the cavity **7** is performed also from the interspace between the abutting surfaces **30** and **31**, a high degree of vacuum can be achieved, thus enabling a more reliable gas removal from within the die **1**. Since the sealing member **15** between the first cover element **14a** and the second cover element **14b** is mounted at a distant position from the die **1**, which in itself is bound to rise to a high temperature, the thermal influence from the die **1** is small. Thus, deterioration of the sealing member **15** is prevented, and durability is improved.

A cooling water flow amount adjustment unit **60** controls cooling of the die **1** during the casting process. The cooling of the die **1** is carried output by allowing cooling water to flow through a cooling water passage **60a**, which is formed in the base die **4**. Specifically, with the timing of the high-speed injection by the plunger tip **11**, a valve (not shown) is opened to allow cooling water to flow for a certain period of time (e.g., a period of time until the die is opened and the

molding is taken out).

The cooling water flow amount adjustment unit **60** in the present preferred embodiment is also able to control the cooling rate of the cylinder bore forming portion **7a** of the die **1**. In the present preferred embodiment, the cooling water passage **60a** extends into the interior of the cylinder bore forming portion **7a**, thus making it possible to control the cooling rate of the cylinder bore forming portion **7a** by controlling the amount of cooling water. Therefore, it is possible to cool the area of the slide surface of the molding (i.e., a portion of the melt located near the slide surface) at a desired cooling rate.

As already described, by cooling the area of the slide surface at a cooling rate of no less than about 4℃/sec and no more than about 50℃/sec, it is ensured that the average crystal grain size of the primary-crystal silicon grains **1011** falls within the range of no less than about 12 μm and no more than about 50 μm, and that the average crystal grain size of the eutectic silicon grains **1012** is equal to or less than about 7.5 μm.

The controlling of the cooling rate may be performed, as shown in FIG. **5**, for example, by detecting temperature of the neighborhood of the slide surface by a temperature sensor **61** which is placed inside the cylinder bore forming portion **7a** of the base die **4**, and adjusting the flow amount of the cooling water so as to equal a desired cooling rate while monitoring the actual temperature through temperature management by a data recorder **62**. If the cooling rate is too fast, the silicon crystal grains will not grow to a grain size which can realize sufficient abrasion resistance. Therefore, the cooling is preferably performed in such a manner that a relatively slow cooling rate is initially used, and a faster cooling rate is used to stop growth immediately before the silicon crystal grains become gigantic.

Before beginning casting, the slide die **5** is placed in a predetermined place, and thereafter the movable die **3** is abutted against the stationary die **2** to close the die, whereby the cavity **7** is formed. At this time, the inside of the cover **14** is sealed upon abutment of the first cover element **14a** against the second cover element **14b**, with the

sealing member **15** interposed therebetween. By thus performing the die-closing step (of abutting together the stationary die **2** and the movable die **3** to form the cavity **7**) simultaneously with the sealing step (of covering the die **1** with the cover **14** to effect sealing), the cast cycle time can be reduced. Note however that these steps do not need to be performed simultaneously. Alternatively, the stationary die **2** and the movable die **3** may be first closed together to form the cavity **7**, and thereafter the die **1** may be covered with the cover **14** to effect sealing.

Now, the operation of the high-pressure die cast apparatus shown in FIG. **5** will be described in chronological order (from time t0 to time t6).

Time t0: The plunger tip **11** is in its original position ("behind" the melt-feeding inlet **12**), and the melt-feeding inlet **12** is open. The interior of the die **1** is exposed to the atmosphere via the melt-feeding inlet **12**. In this state, one shot worth of aluminum alloy melt is injected into the injection sleeve **9** from the melt-feeding inlet **12**. After the melt is injected, the plunger tip **11** moves forward at a slow

speed, thus thrusting forward the melt in the injection sleeve **9**.

Time t1: The tip sensor **13** detects the plunger tip **11**. Since the plunger tip **11** is situated ahead of the melt-feeding inlet **12** in this state, the interior of the cover **14** is being sealed in a completely air tight manner. At this point, the solenoid valve **20a** is driven to evacuate the interior of the cover **14**.

This evacuation is performed so that evacuation of a space **33** between the die **1** and the cover **14** and evacuation of the cavity **7** occur simultaneously. Therefore, an efficient decompression step is carried out, whereby the cast cycle time is reduced.

Note that an evacuation path for the cavity **7** may be distinct from an evacuation path for the space **33** between the die **1** and the cover **14**, such that the two evacuations are performed with different timings. For example, if the space **33** between the die **1** and the cover **14** is evacuated before the cavity **7**, any liquid release agent which may have strayed into and adhered to interspaces such as the abutting surface

of the die **1** and the surface of the slide die **5** facing the slide surface can be directly sucked toward the space **33**, without being sucked into the cavity **7**. Therefore, excess release agent is prevented from flowing into the cavity **7** and mixing with the melt, whereby defects such as pinholes can be prevented.

Through the evacuation as described above, the interior of the cavity **7** of the die **1** is decompressed, whereby the degree of vacuum is gradually increased. The plunger tip **11** keeps moving forward at a slow speed, thrusting the melt toward the cavity **7**. If evacuation is begun after the plunger tip **11** has moved past the melt-feeding inlet **12**, atmospheric air is prevented from being sucked into the die **1** via the melt-feeding inlet **12**. As a result, occurrence of pinholes can be prevented with an increased certainty, and the melt surface is prevented from being locally cooled by the atmospheric air, so that a cast article with uniform and stable quality can be obtained.

Time t2: The progression speed of the plunger tip **11** is switched from slow to fast when the melt has reached the

inlet of the cavity **7**, after which the melt is rapidly supplied into the cavity **7**.

Time t3: The cavity **7** is completely filled with the melt, whereby injection is completed. Since the melt pushes up the ON/OFF valve **18** of the ventilation passage **17** at this time, the melt is prevented from spurting out of the ventilation passage **17**. At the time when a high-speed injection is performed with the plunger tip **11**, cooling water is allowed to flow through the cooling water passage **60a** which is provided inside the cylinder bore forming portion **7a**, so that the area of a portion of the melt to become the slide surface (i.e., the surface facing the cylinder bore) is cooled at a cooling rate of no less than about 4℃/sec and no more than about 50℃/sec.

Time t4: The vacuum pump **21** is stopped, and the decompression through evacuation is completed. At this point, the interior of the cover **14** is still in a decompressed state.

Time t5: The leak valve **16** is opened to expose the interior of the cover **14** to the atmosphere. As atmospheric air flows in through the leak valve **16**, the air pressure

inside the cover **14** becomes closer to the atmospheric pressure with lapse of time.

Time t6: The air pressure inside the cover **14** completely returns to the atmospheric pressure. At this point, the die **1** is opened, and the molding (cast article) is taken out.

By using the above-described production method, the cylinder block **100** shown in FIG. **2** was actually prototyped, and its abrasion resistance and strength were evaluated. Portions of the results are shown below. As the aluminum alloy, an aluminum alloy of a composition shown in Table 1 was used.

Table 1

Si	Cu	Mg
20wt%	2.5wt%	0.5wt%
Fe	P	Al
0.5wt%	200 wtppm	remainder

As silicon, high-purity silicon was used. The calcium content in the aluminum alloy was equal to or less than about 0.01wt%. As a method of slag removal at the time of melting,

only argon gas bubbling was performed, and the sodium content in the aluminum alloy was equal to or less than about 0.1wt%. By ensuring that the calcium and sodium contents are equal to or less than about 0.01wt% and equal to or less than about 0.1wt%, respectively, the silicon crystal grain micronization effect of phosphorus can be conserved, and a metallographic structure which has excellent abrasion resistance can be obtained.

By using the aluminum alloy of the aforementioned composition, casting was performed by the high-pressure die cast apparatus shown in FIG. **5**. Cooling of the cylinder bore forming portion **7a** was performed by allowing cooling water to flow through the cooling water passage **60a** while detecting temperature with the temperature sensor **61**, so that the cooling rate was no less than about 25℃/sec and no more than about 30℃/sec, until the temperature came in the range of no less than about 400℃ and no more than about 500℃. The cylinder block which was taken out of the die **1** was subjected to a heat treatment (solution treatment) at about 490℃ for about 4 hours, then cooled with water, and further subjected

to a heat treatment (aging process) at about 200°C for about 4 hours. Thereafter, a honing process was performed for the cylinder block.

For comparison, casting was also performed by using an aluminum alloy of the same composition, by a sand mold and without cooling the cylinder bore forming portion. After the sand mold casting, a solution treatment, an aging process, and a honing process similar to those performed for the prototype were performed.

With respect to the resultant prototype and comparative cylinder blocks, their slide surfaces were observed with a metallurgical microscope. FIGS. **6A** and **6B** and FIGS. **7A** and **7B** show metallurgical microscope photographs of the respective slide surfaces. FIGS. **6A** and **6B** show the slide surface **201** of the comparative example, which was cast by a sand mold. FIGS. **7A** and **7B** show the slide surface **101** of the prototype, which was cast by high-pressure die cast. Note that reference numerals are added in FIG. **6A** and FIG. **7A**, and circles with a diameter of about 50 μm are shown in FIG. **6A**.

As seen from FIGS. **6A** and **6B**, on the slide surface **201** of the comparative example, a large number of primary-crystal silicon grains **2011** with grain sizes over about 50 μ m are present. On the other hand, as seen from FIGS. **7A** and **7B**, the primary-crystal silicon grains **1011** on the slide surface **101** of the prototype have grain sizes of about 50 μ m or less, thus indicating that, as compared to the comparative example, minute primary-crystal silicon grains **1011** are uniformly distributed.

Furthermore, it can be seen that the eutectic silicon grains **1012** (which are mainly of a needle-like shape, with only some being granular) which have formed on the slide surface **101** of the prototype are finer than the eutectic silicon grains **2012** (most of which are of a needle-like shape) which have formed on the slide surface **201** of the comparative example.

With respect to both the comparative example and the prototype, an average crystal grain size of the silicon crystal grains was calculated. The "grain size" as used herein is the diameter of a corresponding circle. Surface

data of a target area was input to a computer, and an average crystal grain size was calculated by using commercially-available software (win ROOF from Mitani Corporation).

The primary-crystal silicon grains **2011** on the slide surface **201** of the comparative example had an average crystal grain size of about 60 μm or more. On the other hand, the primary-crystal silicon grains **1011** on the slide surface **101** of the prototype had an average grain size of about 24 μm. Furthermore, the eutectic silicon grains **1012** on the slide surface **101** of the prototype had an average crystal grain size of about 6.4 μm.

The slide surface **201** of the comparative example had a vacancy ratio (defined as a ratio of the area of an aluminum solid solution **2013** containing copper and the like to the overall area of the slide surface **201**) of about 15%. On the other hand, the slide surface **101** of the prototype had a vacancy ratio (defined as a ratio of the area of an aluminum solid solution **1013** containing copper and the like to the overall area of the slide surface **101**) of about 35%.

With respect to both the comparative example and the

prototype, in an arbitrary rectangular region of the slide surface having an area of approximately 800 μm×1000 μm, the number of circular regions with a diameter of about 50 μm which did not contain any silicon crystal grains of a crystal grain size of about 0.1 μm or more was counted by visual inspection. It was confirmed that this number was five or less for the prototype. On the other hand, many such circular regions exist in the comparative example, as is clear from FIG. **6A**. Thus, it can be seen that the silicon crystal grains on the slide surface are dispersed more uniformly in the prototype than in the comparative example.

With respect to both the comparative example and the prototype, a grain size distribution of the silicon crystal grains on the slide surface was examined. The results are shown in FIGS. **8** and **9**. FIG. **8** is a graph for the comparative example, which was cast by a sand mold. FIG. **9** is a graph for the prototype, which was cast by high-pressure die cast.

As can be seen from FIG. **8**, the silicon crystal grains which have formed on the slide surface **201** of the comparative

example have a grain size distribution such that a peak exists in the crystal grain size range of no less than about 10 μ m and no more than about 15 μ m and another peak exists in the crystal grain size range of no less than about 51 μ m and no more than about 63 μ m. The silicon crystal grains whose crystal grain sizes fall within the range of no less than about 10 μ m and no more than about 15 μ m are eutectic silicon grains, whereas the silicon crystal grains whose crystal grain sizes fall within the range of no less than about 51 μ m and no more than about 63 μ m are primary-crystal silicon grains.

On the other hand, as can be seen from FIG. **9**, the silicon crystal grains which have formed on the slide surface **101** of the prototype have a grain size distribution such that a peak exists in the crystal grain size range of no less than about 1 μ m and no more than about 7.5 μ m and a peak exists in the crystal grain size range of no less than about 12 μ m and no more than about 50 μ m. The silicon crystal grains whose crystal grain sizes fall within the range of no less than about 1 μ m and no more than about 7.5 μ m are eutectic

silicon grains, whereas the silicon crystal grains whose crystal grain sizes fall within the range of no less than about 12 μ m and no more than about 50 μ m are primary-crystal silicon grains. Also from these results, it can be seen that smaller silicon crystal grains are formed in the prototype than in the comparative example. Incidentally, a Rockwell hardness (HRB) of the slide surface **101** of the prototype was measured to be about 70.

Next, an engine (or specifically, a 4 cycle water-cooling type gasoline engine) was assembled by using each of the prototype and comparative cylinder blocks, and the engines were subjected to an abrasion test. The slide surface of a piston to be inserted into the cylinder bore was iron-plated to a thickness of about 15 μ m. The engine was operated with a revolution of about 9,000 rpm for about 10 hours.

FIG. **10** shows an enlarged photograph of the slide surface **201** of the comparative cylinder block **200** after being subjected to an abrasion test. As shown in FIG. **10**, prominent scratches **203** were left on the slide surface **201**,

throughout the region below a top dead center **206** of the piston ring, indicative of the poor durability of the comparative cylinder block **200**.

FIG. **11** shows an enlarged photograph of the slide surface **101** of the prototype cylinder block **100** after being subjected to an abrasion test. As shown in FIG. **11**, no scratches were left on the slide surface **101** in the region below a top dead center **106** of the piston ring, indicative of the excellent durability of the prototype cylinder block **100**.

As can be seen even from the above results alone, in the case of sand mold casting, no particular cooling of the cylinder bore forming portion is performed, and the cooling rate of the area of the slide surface is uncontrolled, so that the silicon crystal grains which form on the slide surface become gigantic, thus lowering the durability of the cylinder block. This is also true of conventional die casting using a die. In a mass production step using die casting, heat is likely to remain in the cylinder bore forming portion of the die, thus allowing the silicon crystal grains to become gigantic. On the other hand, in the

production method of the present preferred embodiment, the cooling rate of the area of the slide surface is controlled so as to be within a predetermined range. Therefore, silicon crystal grains of a preferable average crystal grain size (or a preferable grain size distribution) are formed on the slide surface, whereby the abrasion resistance and strength of the cylinder block can be greatly improved.

From the standpoint of preventing the silicon crystal grains from becoming gigantic, as already described, it is also preferable to prescribe the calcium content to be equal to or less than about 0.01wt%. The calcium in the aluminum alloy forms a compound with phosphorus, which should function as a micronizing agent for the silicon crystal grains, and thus undermines the micronization effect of phosphorus. Therefore, as shown in FIG. **12**, the primary-crystal silicon grains may become gigantic when the aluminum alloy contains more than about 0.01wt% calcium. On the other hand, if the calcium content is equal to or less than about 0.01wt%, the silicon crystal grain micronization effect introduced by phosphorus can be obtained more securely.

Moreover, if minute silicon crystal grains are dispersed uniformly on the slide surface, the oil pockets to be formed between the silicon crystal grains also become small, thus enabling secure retention of a lubricant in the oil pockets, resulting in improved lubricity and improved abrasion resistance. As schematically shown in FIG. **13**, on the slide surface **101**, silicon crystal grains **1010** protrude from the aluminum solid solution (matrix) **1013** containing copper and the like, thus allowing a lubricant **1015** to be retained in dents **1014** between the silicon crystal grains **1010**. By allowing minute silicon crystal grains to be uniformly dispersed and ensuring that the diameter of the dents **1014** is in the range of no less than about 1 μ m and no more than about 7.5 μ m, a more secure lubricant retention is enabled due to surface tension, thus making for improved lubricity and abrasion resistance.

Next, in order to ascertain the relationship between the cooling rate for the area of the slide surface and the average crystal grain size and abrasion resistance of the silicon crystal grains, a plurality of cylinder blocks were

produced under the same conditions as those for the above-described prototype, while varying the cooling rate for the area of the slide surface.

An engine was assembled by using each of the plurality of cylinder blocks thus produced, and an abrasion test was performed. As a result, it has been confirmed that hardly any scratches occur in the cylinder blocks which were cast under the condition that the cooling rate was no less than about 4 ℃/sec and no more than about 50 ℃/sec, thus indicative of good abrasion resistance.

Moreover, with respect to those cylinder blocks which were cast under the condition that the cooling rate was no less than about 4℃/sec and no more than about 50℃/sec, the slide surface was observed with a metallurgical microscope. As a result, it has been confirmed that the average crystal grain size of the primary-crystal silicon crystal grain on the slide surface was no less than about 12 μm and no more than about 50 μm, and that the eutectic silicon grains had an average crystal grain size of no more than about 7.5 μm. The Rockwell hardness (HRB) of the slide surface was in the

range of no less than about 60 and no more than about 80.

FIGS. **14A** to **14E** show changes in the average crystal grain size of the primary-crystal silicon grains and the vacancy ratio when the cooling rate was varied. As shown in FIG. **14A**, when the cooling rate was equal to or less than about 1℃/sec, the average crystal grain size was as large as about 56.5 μ m, indicative of the gigantic size of the primary-crystal silicon grains. On the other hand, when the cooling rate was no less than about 4℃/sec and no more than about 50℃/sec, as shown in FIGS. **14B** to **14E**, the primary-crystal silicon grains had an average crystal grain size in the range of no less than about 12 μ m and no more than about 50 μ m.

Moreover, an engine was assembled by using a cylinder block which had been cast under the condition that the cooling rate for the slide surface was faster than about 50℃/sec, and an abrasion test was performed, which revealed scratches all over the slide surface. The slide surface was observed with a metallurgical microscope, which revealed that the primary-crystal silicon grains had an average crystal

grain size of about 10 μm or less. No eutectic silicon grains were observed.

Actually, the cooling rate does not stay constant from the beginning to end of the casting process. FIG. **15** shows a relationship between temperature and time after a casting process is begun. In the present specification, the cooling rate in the casting process is defined as (T0-T3)/(t3-t0), based on a melt-feeding temperature T0, a take-out temperature T3, a cast start time t0, and a take-out time t3. Table 2 below shows an exemplary relationship between the cooling rate and the melt-feeding temperature, take-out temperature, and cycle time.

Table 2

melt-feeding temperature (℃)	take-out temperature (℃)	cycle time (sec)	cooling rate (℃/sec)
750	500	10	25
750	500	60	4
750	300	10	45
750	300	60	8
800	500	10	30
800	500	60	5
800	300	10	50
800	300	60	8

The size of the primary-crystal silicon grains is determined as (T1-T2)/(t2-t1), based on a solidification start temperature T1, a eutectic temperature T2, a solidification start time t1, and a time t2 at which the eutectic temperature is reached. On the other hand, the size of the eutectic silicon grains is determined as t2'-t2, based on a time t2' at which the crystallization of the eutectic silicon grains ends. In general, as the size of the primary-crystal silicon grains increases, the size of the eutectic silicon grains also increases; as the size of the primary-crystal silicon grains decreases, the size of the eutectic

silicon grains also decreases.

As described above, the cylinder block of various preferred embodiments of the present invention has excellent abrasion resistance and strength, and therefore is suitably used for various engines including engines for automotive vehicles. In particular, the cylinder block of the present invention is suitably used for an engine which is operated at a high revolution, e.g., an engine of a motorcycle, and can greatly improve the durability of the engine.

FIG. **16** shows an exemplary engine **150** incorporating the cylinder block **100** of a preferred embodiment of the present invention. The engine **150** includes a crankcase **110**, the cylinder block **100**, and a cylinder head **130**.

In the crankcase **110**, a crankshaft **111** is accommodated. The crankshaft **111** includes a crankpin **112** and a crankweb **113**.

Above the crankcase **110** is provided the cylinder block **100**. A piston **122** is inserted in the cylinder bore of the cylinder block **100**. The slide surface of the piston **122** is iron-plated, and has a surface hardness which is greater than that of the slide surface **101** of the cylinder block **100**.

Note that the slide surface of the piston **122** may be coated with a solid lubricant. In this case, the slide surface of the piston **122** may have a surface hardness lower than that of the slide surface of the cylinder block **100**. The choice as to which one of the slide surface of the piston **122** and the slide surface **101** of the cylinder block **100** should have a higher surface hardness (i.e., which one should have a higher abrasion resistance) is to be made based on various conditions (e.g., model, destination, cost, and the like).

No cylinder sleeve is placed in the cylinder bore, and the inner surface of the cylinder bore wall **103** of the cylinder block **100** is not plated. In other words, the primary-crystal silicon grains **1011** are exposed on the surface of the cylinder bore wall **103**. Note that a cylinder block having a plated cylinder bore wall might be used in combination with a piston having a slide surface on which silicon crystal grains have formed in the aforementioned mode or style. However, the cooling performance will be lower in that case, while abrasion resistance can be secured.

Above the cylinder block **100** is provided the cylinder

head **130**. The cylinder head **130** forms a combustion chamber **131** together with the piston **122** of the cylinder block **100**. The cylinder head **130** includes an intake port **132** and an exhaust port **133**. In the intake port **132**, an intake valve **134** for supplying a gas mixture into the combustion chamber **131** is provided. In the exhaust port, an exhaust valve **135** for discharging air from the combustion chamber **131** is provided.

The piston **122** and the crankshaft **111** are connected via a connection rod **140**. Specifically, a piston pin **123** of the piston **122** is inserted in a throughhole in a small end **142** of the connection rod **140**, and the crankpin **112** of the crankshaft **111** is inserted in a throughhole in a big end **144** of the connection rod **140**, whereby the piston **122** and the crankshaft **111** are connected together. Between the inner surface of the throughhole in the big end **144** and the crankpin **112** is provided a roller bearing **114**.

Since the engine **150** shown in FIG. **16** incorporates the cylinder block **100** of an above-described preferred embodiment of the present invention, the engine **150** has excellent

durability. Since the cylinder block **100** of various preferred embodiments of the present invention is characterized by a high abrasion resistance and strength of the slide surface **101**, there is no need for a cylinder sleeve. Therefore, engine production steps can be simplified, the engine weight can be reduced, and the cooling performance can be improved. Furthermore, since it is unnecessary to perform plating for the inner surface of the cylinder bore wall **103**, it is also possible to reduce production cost.

FIG. **17** shows a motorcycle incorporating the engine **150** shown in FIG. **16**.

In the motorcycle shown in FIG. **17**, a head pipe **302** is provided at a front end of a main-body frame **301**. To the head pipe **302**, a front fork **303** is attached so as to be capable of swinging in right and left directions of the motorcycle. At a lower end of the front fork **303**, a front wheel **304** is supported so as to be capable of rotating.

A seat rail **306** is attached to the main-body frame **301** so as to extend in the rear direction from an upper rear end thereof. A fuel tank **307** is provided above the main-body

frame **301**, and a main seat **308a** and a tandem sheet **308b** are provided on the seat rail **306**.

At the rear end of the main-body frame **301**, a rear arm **309** which extends in the rear direction is attached. At a rear end of the rear arm **309**, a rear wheel **310** is supported so as to be capable of rotating.

In a central portion of the main-body frame **301**, the engine **150** as shown in FIG. **16** is held. The cylinder block **100** of any of the preferred embodiments of the present invention is used in the engine **150**. A radiator **311** is provided in front of the engine **150**. An exhaust pipe **312** is connected to an exhaust port of the engine **150**, and a muffler **313** is attached to a rear end of the exhaust pipe **312**.

A transmission **315** is coupled to the engine **150**. A driving sprocket wheel **317** is attached to an output axis **316** of the transmission **315**. The driving sprocket wheel **317** is coupled to a rear wheel sprocket wheel **319** of the rear wheel **310**, via a chain **318**. The transmission **315** and the chain **318** function as a transmission mechanism for transmitting motive power which is generated by the engine **150** to the driving

wheel.

The motorcycle shown in FIG. **17** incorporates the engine **150** in which the cylinder block **100** of any of the preferred embodiments of the present invention is used, and therefore provides preferable performances.

According to various preferred embodiments of the present invention, there is provided an engine component having excellent abrasion resistance and strength, and a method for producing the same.

The engine component according to preferred embodiments of the present invention can be suitably used for various engines including engines for automotive vehicles, and particularly suitably used for engines which are operated at a high revolution.

It should be understood that the foregoing description is only illustrative of the invention. Various alternatives and modifications can be devised by those skilled in the art without departing from the invention. Accordingly, the present invention is intended to embrace all such alternatives, modifications and variances which fall within

the scope of the appended claims.